METEOROLOGICAL\KSC\L71557\LIGHTNING DETECTION AND RANGING (LDAR)

Information last updated: January 2002

Station: KSC

Facility: L71557 (Environmental Health Building)

External Interfaces:

1. Cloud-to-Ground Lightning Surveillance System (CGLSS)

1.0 SYSTEM DESCRIPTION

The Lightning Detection and Ranging (LDAR) system monitors lightning activity within a 100 km area centered around Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS). LDAR detects in-cloud and cloud-to-ground lightning but does not locate ground strike points or provide peak current estimates. The system detects the VHF radiation emitted by lightning at a frequency of 66 MHz and locates the lightning by time-of-arrival (TOA) measurements. The system is configured with a central antenna and six remote antenna sites which continuously transmit their received signals back to the central site. If the time-of-arrival of the various sites agree within a predetermined certainty, the location of the event is plotted in a three dimensional representation on the LDAR display. The remote sites are located within a 10-km circle around the central site (See Figure -1).

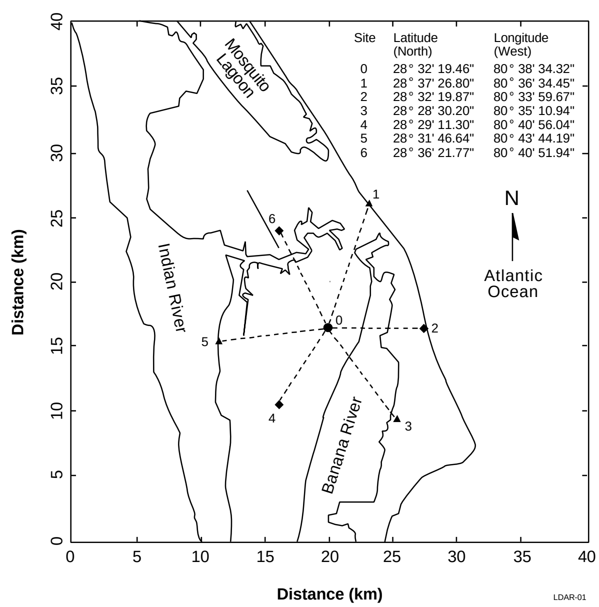

Figure -1. LDAR Remote Site Location Map

1.1 THEORY OF OPERATION

Events are located using the differences in the time-of-arrival of electromagnetic signals. Electromagnetic signals travel from the source to the antenna at the speed of light. The differences between the arrival times can easily be translated into differences in distance from the source to each site.

LDAR is composed of six remote and one central site. Four of the six sites are required to calculate an x, y, z location; thus, the solution is overdetermined and a quality indicator is provided. The central site is required for each solution, which means there are 20 possible site combinations available to calculate an event location. LDAR uses a quality indicator ranging from 0 to 22, with the larger number representing higher consensus among solutions. A quality indication of 8 or more represents an acceptable solution. Only acceptable solutions are displayed.

After a signal is detected each of the sites are checked to verify the measured time delays are valid. The time delays are bound by site geometry and transmission delays. If an electromagnetic signal is moving from a remote site toward the central site, the time delay should be near zero. If a signal is moving from the central site toward a remote site the time delay cannot exceed the transmission time delay plus the distance between the central site and remote sites divided by the speed of light. To account for potential hardware delays 550 nanoseconds is also added. If more than two remote sites have invalid time delays, no solution will be attempted because an acceptable consensus cannot be achieved.

LDAR uses two methods of arriving at a solution. The first is known as the short solution. There are two sets of site combinations that provide optimal geometry for accurately locating events for all azimuths; sites 0-1-3-5 and 0-2-4-6. The quality control algorithm compares the solutions from the two optimal site configurations, and if they agree the solution is accepted and given a weight of 22.

The second method is known as the long solution. If attempts to derive a short solution fail, a solution is attempted by processing all 20 possible site combinations for a consistent solution. After a solution is calculated for each site combination they are assigned a weight. The two optimal site combinations (0-1-3-5 and 0-2-4-6) are assigned a weight of 2 while the remaining 18 combinations are assigned a weight of 1. Only solutions that are acceptable are returned, all others are ignored.

The 3-dimensional accuracy of LDAR has been determined to be ± 300 meters in the x,y,z dimensions within 20 kilometers of the central site. Range errors increase with range beyond 20 km. The bearing accuracy is better than 0.5° regardless of the range.

1.2 SUBSYSTEMS

LDAR is comprised of six subsystems:

1. Data Gathering Subsystem
2. Data Buffering and Backup Archival Subsystem
3. Data Computation Subsystem
4. Communication Subsystem

5. Display Subsystem
6. Calibration Subsystem

Critical elements of each subsystem are identified and discussed below. A high level block diagram of the system is given in Figure -2.

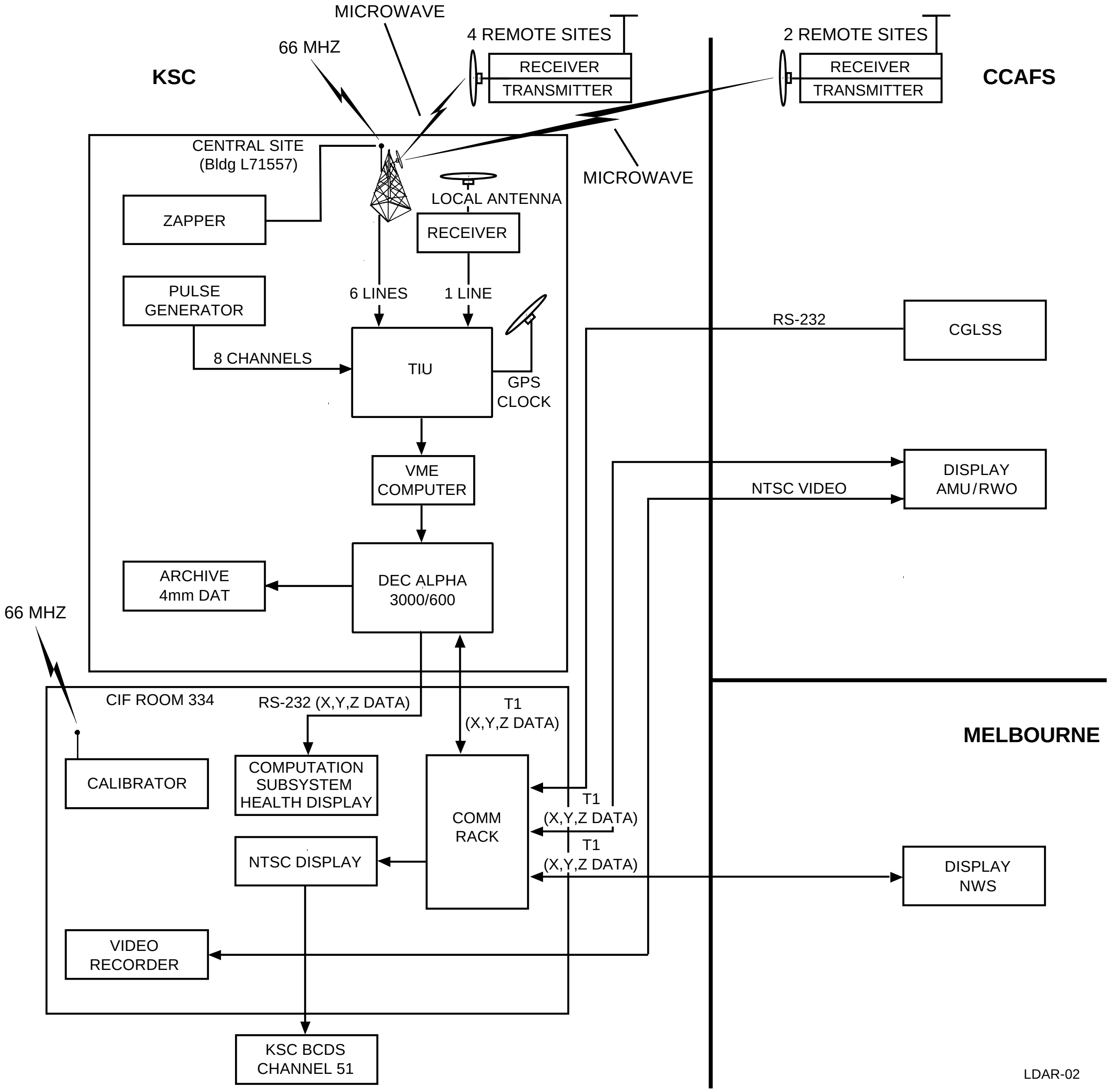

Figure -2. Block Diagram of LDAR

1.2.1 Data Gathering Subsystem

The sensor antennas are conical spirals designed to respond to both horizontal and vertically polarized radio frequency waves. The antennas are Model CSA-630/A, manufactured by Antenna Design and Manufacturing Corporation. The sensors are passive and detect VHF radiation centered at 66 MHz.

When the receiver at the central site detects a signal that exceeds a preset threshold the Timing Interval Unit digitizes 81.92 microseconds of data from each site. Detected pulses are amplified logarithmically and transmitted from the remote sites to the central site via video microwave links.

The Timing Interval Unit (TIU) is located at the central site and processes data pulses via 8 parallel channels that digitize the analog data at a rate of 100 MHz. The TIU determines the time of the peak of the signal within a 81.96 microsecond time window. At the completion of each data cycle, time data, amplitude of the peak, time of trigger, and status data are buffered and made available for output to the Data Computation Subsystem.

1.2.2 Data Buffering and Backup Archival Subsystem

LDAR currently uses a VME-based multi-computer to pass data from the TIU to a DEC Alpha 3000/600 computer that computes x,y,z locations. The VME-based computer is used as a data buffer and backup archival system.

1.2.3 Data Computation Subsystem

The data computation is performed at the central site by a Digital Equipment Corporation (DEC) Alpha 3000/600. At a sustained rate, the system can process in excess of 6000 events per second if only two site combinations are used in the solution. The system can process in excess of 3500 events per second if all 20 possible site combinations are used. If the data set contains only 1 dominant pulse for an 81.96 microsecond window and all sites are operating nominally, the short solution’s two site combinations will dominate. In all other conditions the 20 site combination solutions will be used. The primary output from the computation subsystem is via a T1 data link to the Central Instrumentation Facility (CIF) Building on KSC. The data is output in broadcast mode and no handshaking is required to enable data transmission.

The computation subsystem also ingests lightning location data from the 45 SW Cloud-to-Ground Lightning Surveillance System (CGLSS). The ground strike points are transmitted over an RS-232 circuit at 1200 baud to the LDAR computation subsystem. The CGLSS data is converted from latitude and longitude to x, y, z coordinates in meters relative to the LDAR central site and is plotted on the outer edges of the display panels as an ‘X’ to serve as a reference since LDAR does not locate ground strikes.

The computation subsystem serves as the primary data archival point where all data is stored on 4-mm Digital Audio Tapes (DAT). One 4-mm DAT is capable of storing 1.2 Gigabytes of data that can be used for post event analysis.

1.2.4 Communication System

LDAR utilizes four separate communication subsystems: the microwave subsystem, the Local Area Network (LAN)/Wide Area Network (WAN), the National Television Standards Committee (NTSC) display circuit, and two RS-232 circuits, each of which is explained below.

1.2.4.1 Microwave Links

There are six microwave links used to transmit LDAR waveform data from each of the six remote sites to the central site. These links require a clear line of sight between the remote sites and the central site. Each of the remote sites include a 2-foot diameter microwave antenna mounted atop a wooden pole, 52 feet above ground level. The central site uses 4-foot diameter receiver antennas mounted at the 80-foot level of a tower. The alignment of the microwave antennas and the performance of the microwave links must be maintained such that the receiver Automatic Gain Control (AGC) voltage does not exceed 7 volts for sites 1 through 5 and 8.2 volts for site 6. Table -1 shows the microwave link characteristics.

Table -1. Microwave Link Characteristics

Site Number	Frequency (MHz)	Polarization	Transmitter Power (dBm)	Receiver AGC Voltage (Volts)	Discriminator Voltage (Volts)
1	4450	horizontal	+29	+6.5	+.003
2	4405	vertical	+27	+6.5	+.062
3	4465	horizontal	+25	+6.8	+.030
4	4435	vertical	+28	+6.7	-.034
5	4480	horizontal	+28	+6.6	-.008
6	4420	vertical	+27	+8.0	-.012

1.2.4.2 Local Area Network (LAN)/Wide Area Network (WAN)

LDAR utilizes an independent LAN/WAN to connect with user displays and for maintenance purposes. The LDAR LAN/WAN consists of three T1 circuits. The first connects the LDAR central site with equipment in Room 334 of the CIF building on KSC. This circuit is fiber optic with a pair of modems that provides two-way communications. During normal operations data is broadcast from the LDAR central site to Room 334 of the CIF. The capability exists to communicate from the CIF to the LDAR central site for the purpose of performing remote maintenance and for installing software upgrades.

The second circuit connects Room 334 with Range Weather Operations (RWO) and Applied Meteorology Unit (AMU) displays in the Range Operations Control Center (ROCC) located on CCAFS. The RWO is the primary LDAR user.

The third circuit connects Room 334 to the National Weather Service (NWS) display in Melbourne, Florida. Currently the circuits to the RWO and NWS are bidirectional. In the future these two circuits will be blocked so that no direct communications can originate from the RWO or the NWS to the LDAR central site. This is required so that the full bandwidth is available for LDAR data and to preserve system integrity.

1.2.4.3 National Television Standards Committee (NTSC) Display

LDAR data received in Room 334 of the CIF is displayed on a computer workstation. The output from the display is converted from Red Green Blue (RGB) analog signals to a NTSC standard television signal and is broadcast throughout KSC via the Broadband Communications Distribution System (BCDS) channel 51. The video signal is also routed to the RWO in the ROCC at CCAFS and can be disseminated over the CCAFS Closed Circuit Television (CCTV) network. The capability to disseminate the RWO display over the CCTV network also exists. The video is recorded by National Aeronautics and Space Administration (NASA) on VHS format tapes at a rate of 1 frame per 1.5 seconds.

1.2.4.4 RS-232 Circuits

LDAR utilizes two separate RS-232 circuits. The first previously described and is used to transmit CGLSS data received in Room 334 of the CIF to the computation subsystem for conversion and display. The second is used to connect the LDAR computation computer (DEC Alpha 3000/600) to a data terminal in Room 334 of the CIF. The terminal is used to monitor the status of the computation subsystem and to display several operational parameters such as the number of triggers, trigger threshold, etc.

1.2.5 Display Subsystem

The display subsystem is comprised of a computer with an Ethernet interface capability, a display terminal, and appropriate software. NASA has many display subsystems in many different configurations located at KSC but the primary user of LDAR is the RWO located in the ROCC at CCAFS. This discussion will be limited to the display subsystem located at the RWO.

The RWO display terminal consists of a DEC 3000 computer and is the real-time interface with the LDAR system. The display subsystem is used to graphically portray LDAR data for interpretation by trained meteorologists in the RWO.

The LDAR display is comprised of four major panels, status indicators, and a pull down menu. Each LDAR point within the x,y,z region of the display is represented in each of the four panels. The data is plotted as points in the x-y, x-z, and y-z projections. The fourth panel is a histogram of the number of events that are plotted each minute for the last 5-minutes. LDAR displays 5-minutes of data and the brightness of the points displayed determine which minute the data was plotted. The most recent minute of data is the brightest which makes it the most distinguishable. The display is redrawn each minute to update the time scale on the histogram and at this time the brightest level for each plotted data point is adjusted to reflect the time it was received. The brightest points being the most recent and the dimmest representing the oldest data. See Figure - 3 for an example of the LDAR display.

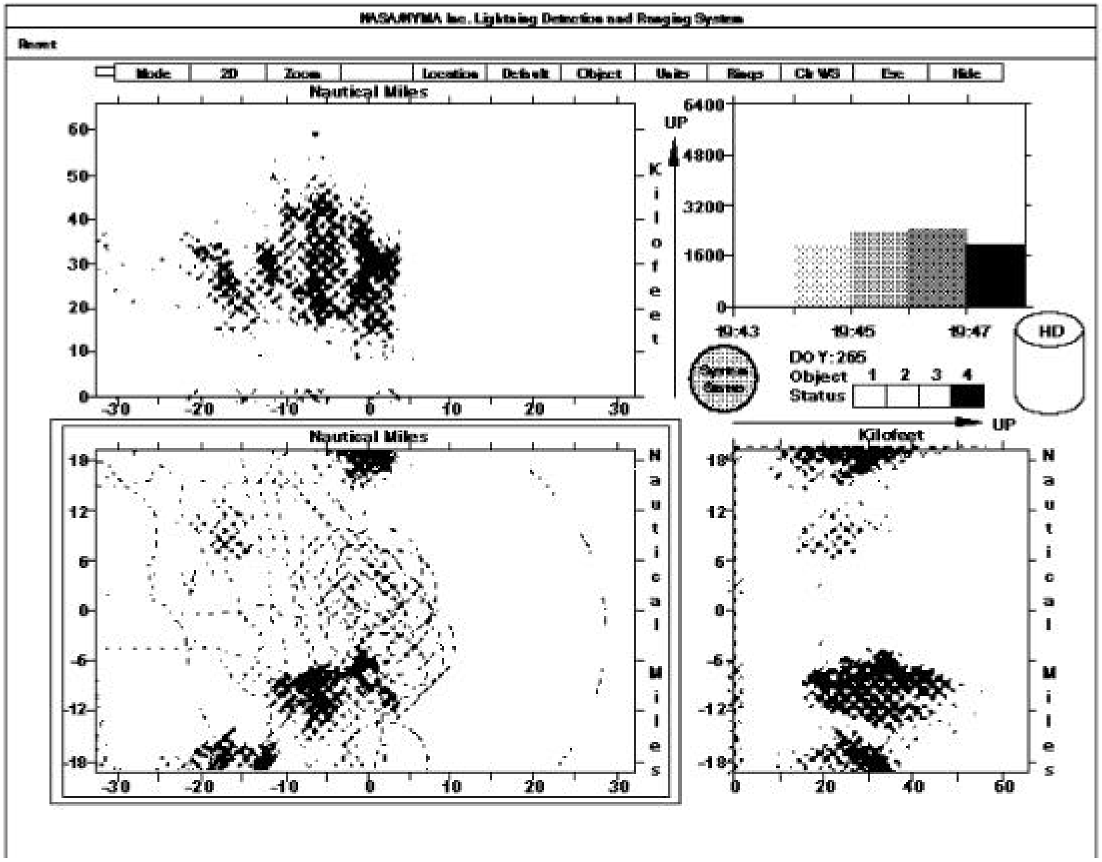

Figure -3. LDAR Display

1.2.5.1 Plan View Panel (X-Y Panel)

This panel is located on the lower left of the display and uses a Cartesian coordinate system. The horizontal axis of the panel represents distance in the east-west direction and the vertical axis represents distance in the north-south direction. The center of the panel by default is the location of the LDAR central site. Positive x values represent east and positive y values represent north. The option to change the central site default origin is available. The ability to change the units also exists in the pull down menu options, and can be changed between miles, kilofeet, nautical miles, or kilometers. The border surrounding the x-y panel is used to plot data that are outside of the coverage area of the display. This feature is useful in identifying lightning activity within LDAR's range but outside the viewing area. This feature also provides a visual indication of the bearing of the storm cell.

1.2.5.2 Altitude Versus East-West (X-Z Panel)

The x-y panel is located on the upper left side of the display above the x-y panel. This panel depicts the data as a function of altitude and the east-west coordinate. The x-axis of the panel is the same scale and offset as the x-axis of the x-y panel. The altitude scale is menu selectable. All events that are above the z-axis and within the x-y region of the display are plotted in the vertical overflow bin above the x-z panel.

1.2.5.3 Altitude Versus North-South (Y-Z Panel)

The y-z panel is located in the lower right corner of the display and depicts the data as a function of altitude and the north-south coordinate. The y-axis in this panel has the same scale and offset as the y-axis in the x-y panel and the altitude scale is user selectable via the pull down menu.

1.2.5.4 Histogram

The upper right corner of the display contains a histogram that shows the history of LDAR events detected within the display area. The histogram contains five columns with the horizontal axis representing time in one minute intervals and the vertical axis representing the number of events plotted for that minute. The right hand column represents the most recent data (time increases to the right). The column height will increase during the current minute as data is plotted within the x,y,z region displayed. The remaining columns represent data that is older by one minute increments. The shading of the columns is varied to show the age of the data. The data time (UTC) appears at the right side of the display below the histogram. When the pan or zoom option is used the histogram values will change to reflect only the data displayed in the viewing area.

1.2.5.5 Status Indicator

The round circular status indicator near the center of the screen at the point where the four panels intersect is used to indicate the overall operational status of the system. If the indicator is green or yellow the system is functional. A red indicator means that the self check pulses, which are generated by the system calibrator each minute, were not detected or processed.

1.2.5.6 Object Indicators

The rectangular bar to the right of the System Status indicator is composed of four boxes labeled 1 to 4. Each represents a specific site on KSC. The color of the boxes are changed to indicate lightning within a specified area surrounding the site. The detection area is square and the specified distance represent the closest distance from the center of the square to the edge. See Table -2.

Table -2. Display Object Status Box Locations and Color Definitions

Status Box	**Location**	**Color Indicator**		
		> 6 LDAR events within 5 nmiles and 5 minutes	**> 6 LDAR events within 10 nmiles and 5 minutes**	**<= 6 LDAR events within 10 nmiles and/or 5 minutes**
1	SLC 39A	Red	Yellow	Green
2	SLC 39B	Red	Yellow	Green
3	SLF	Red	Yellow	Green
4	KSC Industrial Area	Red	Yellow	Green

1.2.5.7 Date and Other Features

The day of the year (DOY) is shown directly above the objects indicator. LDAR has several features that are available through pull down menus. The operator has the option to change modes between the replay of historical data and displaying live data. The ability to zoom, pan, change units, and to overlay objects are also some of the options available.

1.2.6 Calibration Subsystem

The calibration subsystem consists of three calibration units that are used for system calibration and maintenance. Two of the units radiate signals at 66 MHz, and are designed to emulate lightning. One is located on the central site microwave tower and radiates energy from a monopole antenna at 700 pulses per second. It is known as the Zapper and is used to perform routine maintenance. The other is located at the CIF Building and is known as the Calibrator. Once per minute, on the minute, a trigger is initiated that causes the Calibrator to emit 32 pulses, 100 microseconds apart, through a vertically polarized monopole antenna located on the roof of the building. The pulses are detected by the LDAR system and are used to determine the operational status of the system.

The third calibration unit is a pulse generator with eight independent outputs used to inject signals directly into the video input path of the system. This allows the system to be tested independently of the remote sites and the central site receiver. By selecting the proper time delays for each channel the pulse generator can simulate a lightning source at any location. The pulse generator also makes it possible to test the system over its full operating range of 1 to 10,000 pulses per second.

2.0 SYSTEM CAPABILITIES

LDAR provides 45 WS personnel with a system that characterizes the 3-dimensional extent of lightning around KSC/CCAFS area. This information defines the spatial extent of the lightning danger area and the likelihood of impending cloud to ground lightning.

LDAR is used in real-time to aid in issuing and lifting lightning advisories for KSC/CCAFS ground operations. LDAR provides trained observers with the ability to identify, isolate, and track individual cells; it can also provide indication of storm shear.

Table -3 is a summary of the technical characteristics of the four lightning detection and location systems utilized on the ER. Each of these systems has strengths and weakness relative to the other systems. All four systems must be used in a complementary manner to fully characterize the lightning threat. The data from these systems, when combined with information from other meteorological sensors, and analyzed by appropriately trained meteorological personnel, provides the basis for issuing accurate and timely lightning warnings and forecasts. The data provided is also instrumental in evaluating the Lightning Launch Commit Criteria (LLCC) imposed on each launch operation at the ER.

This is to insure that launch vehicles are not at risk of intercepting either natural or triggered lightning during the first minutes of flight. The four lightning detection systems are:

1. Launch Pad Lightning Warning System (LPLWS)
2. Cloud-to-Ground Lightning Surveillance System (CGLSS)
3. National Lightning Detection Network (NLDN)
4. Lightning Detection and Ranging (LDAR)

Table -3. Technical Characteristics of the Four Lightning Detection Systems Used on the ER.

	LPLWS	CGLSS	NLDN	LDAR
System type	Field mill network	Hybrid[1]	Hybrid[1]	VHF time-of-arrival
Number of sensors	31	6	105[2]	7
Sensor spacing	2-5 km	20 km	200-400 km	6-10 km
Effective range	<20 km	100 km	National	100 km
Lightning detected	All	Cloud-to-ground only	Cloud-to-ground only	All
Flash detection efficiency	>90%[3]	92%[4]	80%[5]	≈ 100%
Lightning process located	Center of charge	Return stroke, ground strike	Return stroke, ground strike	VHF radiation
Local accuracy	2-20 km[3]	0.5 km	≈ 2 km[5]	100 m
Locations per flash	1	1-5	≈ 1 [5,6]	20-1000
Peak location rate	85 min^{-1}	74 min^{-1}	800 min^{-1}	10,000s^{-1}
Display	Stand-alone and MIDDS	Stand-alone and MIDDS	Stand-alone	Stand-alone
Source	Locally developed	Commercial product	Commercial service	Locally developed

[1]Integrated magnetic direction finding/time-of-arrival technology.

[2]After network reconfiguration for hybrid magnetic direction finding/time-of-arrival sensor.

[3]Estimated values, currently under evaluation.

[4]With requirement for ≥ 3 ALDF responding with X^2 <10.

[5]Based on most recent evaluation of system performance when using only magnetic direction finder technology.

[6]System typically resolves only one ground strike point per flash.

3.0 CONCEPT OF OPERATIONS

Except for maintenance down time, LDAR operates 24 hours/day, 7 days/week, and is operated and maintained by a NASA contractor, Command Technologies, Inc. (CTI). On days when the lightning forecast is greater than 20% scheduled maintenance and testing is typically restricted to the hours between 0730 and 1300 so that the system is available during the most critical lightning periods (afternoon hours). Maintenance and/or testing activities can be performed at any time of day when the lightning forecast is less than 20%. Scheduled down time is normally coordinated with the Range in order to minimize impact to operations. The contractor that maintains the system for NASA works weekdays 0730-1600, with the exception of holidays, so if the system fails during off-hours the failure won't get worked until the next scheduled work day. The contractor does provide after-hour coverage during critical operations.

4.0 OPERATIONAL LIMITATIONS

The spare computer for the data computation system is a DEC Alpha 3000/400 which is fully functional, but operates at a reduced level of performance. Failure of the communications link between the central site and the CIF building is a single point of failure and will bring down all displays.

Currently, the display subsystem is unable to keep up with the high rate of data produced by the data gathering and data computation subsystems. This problem is manifested in two ways: (1) the display may run behind real-time by up to 1-minute and is rate dependent, and (2) data may be lost due to the fact that the display may not be able to capture all incoming data and update the display at the same time. The performance of the displays are based on the maximum sustained data rate that the displays can accept without losing or dropping data. The performance is directly related to the size of the internal data buffer that stores incoming data during the display redraw interval.

One of LDAR's biggest problems is corruption from external noise sources. However, these noise signatures are easily identified by a trained observer. A few of the most common are explained below.

Radial Scatter occurs when large storms are active at distances greater than 20 kilometers away from KSC. A small number of events pass the LDAR data quality filters with large errors. The points can be recognized because they usually occur on a line between the storm and the LDAR central site and their height is a function of range. They also occur concurrent with lightning located elsewhere, either on the display or in the overflow bins. When this occurs, normally only 1 or 2 points appear during a flash interval. These points start at the storm height (20 to 40 kft) and decrease in height to near 5 kft near the LDAR central site.

LDAR occasionally tracks electromagnetic interference generated by some aircraft flying at low altitudes in the vicinity of KSC. The aircraft emit RF pulses due to faulty ignition shielding or noisy strobe lights. Helicopters have also been tracked by LDAR, possibly due to RF energy emissions from discharging rotors. These aircraft generally fly below 10 kft and can be recognized by the continuous lines on the LDAR display with durations of several seconds. (Note: lightning flash durations are normally 0.5 seconds.)

LDAR also occasionally tracks jet aircraft above 20 kft. These aircraft appear as a continuously growing line of data points as the aircraft passes through the air space over KSC. It is not unusual for the aircraft to be tracked in excess of a minute. This phenomenon is believed to be caused when an aircraft becomes charged from flying through clouds with ice crystals. When the aircraft discharges it produces RF pulses detectable by LDAR.

LDAR can experience random noise when a local event continuously triggers the central site allowing a few samples to pass the data points will be plotted in the vicinity of the central site and will scatter vertically above the site.

LDAR does not indicate the potential for triggering lightning. LDAR has reduced detection efficiency below 2 kilometers altitude and does not detect and locate events that occur during long continuous radiation (such as return strokes).

5.0 LOGISTICS

NASA contractor CTI is currently responsible for the operation and maintenance of LDAR. The Eastern Range is responsible for the maintenance of the display subsystem located in the RWO on CCAFS. This maintenance is performed by the Range Technical Services Contractor (RTSC) to the Line Replaceable Unit (LRU) level.

6.0 REFERENCE DOCUMENTS

"Lightning Detection and Ranging (LDAR) System Certification Document", Revision 1.2, dated 5 June 1995.